General Instructions: READ THIS PAGE BEFORE YOU BEGIN THE EXAM.

1. Write your name on every page. (5 points off for EACH unnamed page.)
2. For your own benefit, write your answers LEGIBLY in the space allotted. If we cannot read your handwriting, we cannot give you credit for your answer.
3. Do NOT write on the BACK of any page unless you get a TA’s permission FIRST.
4. About writing answers:
   • All questions can be answered briefly.
   • Answer the question that is asked specifically, precisely, and accurately.
   • For full credit, show your calculations.
   • In problems asking for an answer and for a reason, more credit is given for a correct reason.
   • If you are asked for one reason, be sure you write down only the best one.
5. About grading:
   • We give credit for correct and relevant answers. We ignore true, but irrelevant statements.
   • We do, however, deduct points for irrelevant statements that are incorrect.
6. Use a pen or pencil to write your answers, but do NOT use RED INK and DO NOT USE WHITE-OUT of any kind. However, if you use pencil, you cannot request a regrade.

POTENTIALLY USEFUL EQUATIONS:

\[ E_{\text{ion}} = 6.1 \cdot \frac{\log [X]_{\text{out}}}{[X]_{\text{lin}}} \]

\[ V_m = \frac{G_{Na}}{\sum G} E_{Na} + \frac{G_{K}}{\sum G} E_{K} + \frac{G_{Cl}}{\sum G} E_{Cl} \]

\[ W_T = nRT \int \frac{dV}{V} \]

\[ V = IR \]

\[ E = mc^2 \]

\[ I_X = G_X (V_m - E_X) \]

\[ R_{\text{total}} = \sum R_{\text{individual}} \]

SCORE:

Page 2_______
Page 3_______
Page 4_______
Page 5_______
Page 6_______
Page 7_______
TOTAL __________

WAIVER: By signing this waiver I give permission that this exam can be left for me to pick up in the hall on the third floor of Pacific Hall. I realize that this procedure may expose my grade to public scrutiny and my exam to theft. If I do not sign this waiver, I understand I will be able to get my graded exam back only as described in on the course Web site.

____________________________________________________
Signature Date
1. (18 points total) Shown below is a diagram of some of the factors that regulate the concentration of Na\(^+\) in the blood. Na\(^+\) is a major component of the solutes in blood, so increases in blood [Na\(^+\)] activate osmoreceptors in the hypothalamus. These receptors activate two brain regions: the Thirst Center in the hypothalamus and some hormone-secreting neurons in the anterior pituitary that release ADH into the blood. Activity in the Thirst Center causes us to drink water (which is absorbed in the intestines), and ADH has an effect on the kidneys that retains water in the blood. Both of these effects—drinking and water retention—dilute the blood [Na\(^+\)].

A. (5 points) Based on the description of this system, add the signs (+ or -) at appropriate places. (A total of 5 signs are needed.)

B. (7 points) Is this system positive feedback, negative feedback, or a combination of the two, or neither? Briefly explain.

Negative feedback, because there is one negative sign in both of the feedback loops, so any change in any signal will produce a feedback signal of the opposite sign.

C. (7 points) The blood [Na\(^+\)] controls the [Na\(^+\)] in the extracellular space: any increase or decrease in the blood [Na\(^+\)] causes a corresponding change the [Na\(^+\)] in the extracellular space. Draw this relationship on the diagram above.

Is the extracellular [Na\(^+\)] part of the feedback system?

No.

What is this type of relationship called between the extracellular [Na\(^+\)] and the rest of the control system?

It is an indirectly controlled component [or indirectly controlled signal].
2. (15 points total) As a comparative physiologist, you find a new species of lamprey eel at the bottom of a pond in Yellowstone Park. You are amazed to find that this creature has no Na\(^+\), K\(^+\), or Cl\(^-\) in its body; instead the major ions in the intracellular and extracellular fluid are strontium (Sr\(^{++}\)), rubidium (Rb\(^+\)), and bromine (Br\(^-\)). You determine the concentrations of each of these ions in a set of motor neurons and in the extracellular fluid, as well as the ionic conductances at the resting potential:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Intracellular concentration</th>
<th>Extracellular concentration</th>
<th>Conductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr(^{++})</td>
<td>10 mM</td>
<td>100 mM</td>
<td>100 mS</td>
</tr>
<tr>
<td>Rb(^+)</td>
<td>60 mM</td>
<td>6 mM</td>
<td>200 mS</td>
</tr>
<tr>
<td>Br(^-)</td>
<td>8.5 mM</td>
<td>85 mM</td>
<td>100 mS</td>
</tr>
</tbody>
</table>

A. (9 points) Calculate the equilibrium potential for each ion. Show your calculations.

\[\begin{align*}
E_{Sr} &= \frac{61}{2} \log \left( \frac{100}{10} \right) = 30.5 \ (\log 10) = 30.5 \ mV \\
E_{Rb} &= \frac{61}{1} \log \left( \frac{6}{60} \right) = 61 \ log (0.1) = -61 \ mV \\
E_{Br} &= \frac{61}{-1} \log 85/8.5 = -61 \ (\log 10) = -61 \ mV
\end{align*}\]

B. (6 points) Calculate the resting potential of the neurons, assuming that Sr\(^{++}\), Rb\(^+\), and Br\(^-\) are the only ions that affect the resting potential. Show your calculations.

\[V_{rest} = \frac{G_{Sr} E_{Sr}}{G_{total}} + \frac{G_{Rb} E_{Rb}}{G_{total}} + \frac{G_{Br} E_{Br}}{G_{total}}\]

\[V_{rest} = \frac{100}{400} (30.5) + \frac{200}{400} (-61) + \frac{100}{400} (-61)\]

\[V_{rest} = \frac{3050}{400} - \frac{12200}{400} - \frac{6100}{400} = \frac{-15250}{400} = -38.1 \ mV\]
3. (16 points total) Pyrethrin is a natural insecticide used by chrysanthemums to kill leaf-munching insects. Voltage-clamp experiments have shown that pyrethrin molecules bind to the voltage-gated $\text{Na}^+$ channels in insect axons and keep the $\text{Na}^+$ inactivation gates from closing.

A. (6 points) The top graph below shows the voltage changes seen during a typical action potential in an insect axon. On the blank graph below the action potential graph, draw the $\text{Na}^+$ and $\text{K}^+$ conductances during the action potential. Label the two conductances that you draw. (The vertical lines are provided to be reference points between the two diagrams.)

B. (10 points) On the same axes, draw dotted lines to indicate what each of the features (action potential voltage, $\text{Na}^+$ conductance, $\text{K}^+$ conductance) would look like in the presence of pyrethrin. Briefly explain why the dotted lines differ in any way from the original lines. (If you cannot draw some feature, explain what information is missing.)
4. (10 points) A scientist discovers a new species of frog that produces a toxin that specifically blocks Ca$$^{++}$$ channels at neuron-to-neuron synapses. What will happen to the Knee-jerk Reflex if this toxin were injected into the dorsal horn of the lumbar spinal cord? Briefly explain your answer.

Because the Ca$$^{++}$$ channels in the presynaptic terminals of the stretch receptor are blocked, the action potentials arriving at their terminals cannot release transmitter, so no motor neurons to the stretched muscle (or its synergists) will be activated, so there will be no muscle contraction.

[Input to the interneurons that inhibit the motor neurons to the antagonistic muscles will also be blocked, so the muscle antagonists will not relax. This is a secondary effect, and not one that a Neurologist would look for, but if you mentioned it, good for you!]

5. (10 points total) Hyperkalemia is a condition in which an animal’s blood has higher than normal levels of potassium. In this condition, the concentration of K$$^+$$ in the fluid outside of all cells in the body is increased, but the intracellular concentration of K$$^+$$ is normal.

A. (2 points) How would hyperkalemia affect the resting potentials of neurons? Briefly explain.

The neurons would be depolarized because the equilibrium potential for K$$^+$$ would be less negative; the $[K^+]_\text{out} / [K^+]_\text{i}$ ratio would be lower.

B. (8 points) How would the flexion reflex be affected by hyperkalemia? (Briefly explain by discussing the effects of increased K$$^+$$ levels on each of the neurons in the reflex pathway.)

The membrane potentials of all neurons would be depolarized, so that (1) because their receptor potentials would produce greater depolarizations, the pain receptors will produce more action potentials, causing (2) larger summed synaptic potentials on all the interneurons, so they would fire action potentials at a higher rate than normal, which would (3) activate more flexor motor neurons, causing them to fire at a higher rate, which would (4) cause a larger contraction of the flexor muscles.

[Similarly, the inhibitory inputs onto extensor muscles would be larger, making the flexion movements even larger.]

[There would be an increase in the crossed-extension reflex, too, but that is not a necessary part of the answer.]
6. (9 points total) A doctor found that a patient had lost all sensation of pain in her right leg. Her motor movements were fine, and she was still able to maintain the feeling of light touch in both legs. Further investigation showed that the patient also lost sensation of pain in her right hand.

A. (3 points) A pre-med student shadowing the doctor speculated that the patient must have an injury in her left dorsal column in the lumbar spinal cord. Is the student correct? Explain your answer.

The pre-med had the wrong pathway. Pain sensation is transmitted across the spinal cord to the opposite side at the level of the input to the spinal cord. The pain signal is transmitted to the brain via the contralateral anterolateral pathway. Because the patient had lost pain sensation in her hand, too, the injury—assuming it is a single injury—is likely to be in the left anterolateral tract, between the brain and the spinal level receiving input from the hand, i.e., somewhere in the upper cervical spinal cord.

B. (3 points) Would this patient’s injury also affect motor activity in her right hand? Why?

Not necessarily, because motor control is transmitted by separate pathways in the spinal cord. If the injury is localized to the anterolateral tract, no motor problems would be apparent.

C. (3 points) Would you expect that this patient’s injury to affect proprioception in her left leg? Why?

No, because proprioception is transmitted by pathways (the dorsal columns) completely separate from pain.

7. (10 points total) Dopamine binds to metabotropic dopamine receptors in the mammalian brain, which opens ion channels to both Na⁺ and K⁺.

A. (3 points) Briefly describe the pathway used by dopamine to open ion channels.

Because it is metabotropic, the dopamine receptor releases a g-protein into the cytoplasm that binds to the Na⁺/K⁺ ion channel, which is separate from the receptor molecule.

B. (3 points) Cocaine, a recreational drug that produces an intense “high”, inhibits the reuptake of dopamine by competitively binding to the dopamine transporter (DAT). How will this property of cocaine affect the synaptic dopamine concentration and the resultant EPSP?

A major mechanism for stopping the action of dopamine is by re-uptake into the presynaptic terminal. Blocking DAT would, therefore, greatly increase the amount of time that dopamine would be in the synaptic cleft to bind to the postsynaptic receptors, which would give a greater and more prolonged response.

C. (4 points) The Ventral Tegmental Area (VTA) of the midbrain is one of the dopaminergic pathways in the brain connects to the limbic system (especially the nucleus accumbens and the amygdala) as well as to the prefrontal cortex. This dopamine system is thought to be a “reward” pathway, based upon a variety of experiments. (For instance, hungry rats will work harder to receive electrical stimulation of the VTA than to receive food.) Explain how cocaine could produce “increased energy, mental alertness, and reduced fatigue” (description from the National Institute of Drug Abuse web page).

Cocaine would prolong the action of dopamine at synapses onto the neurons of the nucleus accumbens and the amygdala, which would be interpreted as a greatly increased “reward”. This strongly positive feeling is likely to be a strong motivation for the person to increase their activity level to reproduce the rewarded condition.
8. (12 points total) For the following three groups of statements (A, B, and C), circle every letter that makes a TRUE statement. Note that any number of statements may be true—including none of them—so that if you do not circle a letter you are indicating that you believe that the statement is false. (You lose a point for every incorrect answer circled and for every correct answer not circled.)

A. Control signals vary in several different ways:
   a. some signals are carried by the nervous system and others are carried by the endocrine system.
   b. despite large differences in onset latency, all the signals decay at the same rate after the signal is turned off.
   c. the targets for neural signals can be muscles, neurons, glands, and adipose tissue; the targets for endocrine signals can be every cell type in the body.
   d. there are two levels for the responses to both neural and endocrine signals: a specific cellular response and a more general systemic response.

B. Glial cells:
   a. outnumber neurons in the CNS by more than 10X.
   b. produce the myelin sheathes on axons in nerves, but not on axons in tracts within the CNS.
   c. include satellite cells, which form supportive capsules around neuron somata in ganglia.
   d. include astrocytes, star-shaped cells with many functions, including the formation of the blood-brain barrier.

C. In the evolution of nervous systems:
   a. the first multicellular animals to develop distinct neurons were jellyfish and sea anemones.
   b. action potentials and synaptic potentials are the same in all nervous systems from jellyfish to humans.
   c. having greatly expanded brains in the head (“cephalization”) probably resulted from the advantage of having complex, specialized sensory structures in the part of the body that first contacts the environment as the animal moves.
   d. in vertebrates, the most dramatic change in brain evolution is the increase in size of the cerebellum.

[Correct answers are in bold type.]